

AN ANALYSIS OF THE MADISON, WIS., AEROLOGICAL DATA, WITH AN APPLICATION OF THE BJERKNES THEORY

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Published investigations of the Bjerknes theory of cyclones in this country are limited mostly to studies of individual storms. It is recognized that a qualitative analysis of the structure of the free atmosphere in cyclones necessarily requires simultaneous observational data from entire areas of pressure disturbances. In this paper an attempt is made to apply the Norwegian theory to the available free-air data obtained at a single station. Applicability of the theory to American weather maps is comprehensively discussed by Rossby and Weightman (1) in the MONTHLY WEATHER REVIEW, December, 1926.

The present work is based on the data secured from a series of 3333 single theodolite observations used in connection with a study of the two daily weather maps covering the period from May, 1919, to February, 1927, inclusive. The observations were made twice daily, 7 a. m. and 3 p. m., ninetieth meridian time, to July 31, 1921, and then daily, at 3 p. m. to the termination of the series. Winds at the observing point (elevation 307 meters above sea level) located on top of a four-story building, are probably little influenced by surrounding objects.

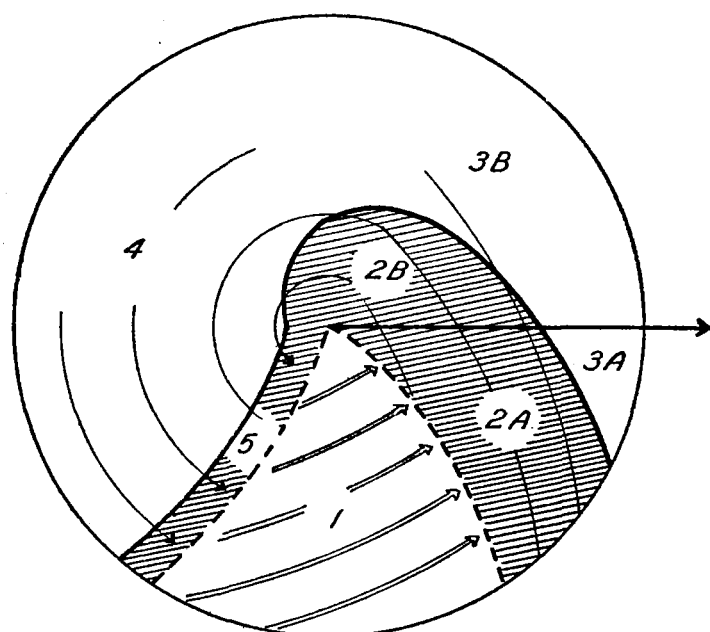


FIG. 1.—Bjerknes idealized cyclone, with numbering of various sectors as used in this study

In the investigation of the free-air winds in cyclones, division into sectors as presented in Figure 1—the Bjerknes idealized cyclone—was used, with numbering of the various sectors for convenience. The characteristics of the different sectors are well known. The broad rain band and the preceding rainless area have been divided into two sections each, one north and the other south of the path of the traveling cyclone. A total of 435 observations for the entire cyclone was obtained, the number of ascensions in the different sectors being given in Table 1.

In attempting to determine the position of an observation in the low, no detailed study of each map was possible, but a discrimination of distinctive weather types

appearing on the maps was aided by continued reference to retained weather records. The selections were not limited to well pronounced lows, but included all observations possible of classification. Use of the four seasons was considered advisable.

Figure 2 (*a, b, c, d, and e*) has been prepared from the data contained in Tables 5 and 6. Free-air resultant winds in Lows are represented, by arrows flying with the wind, with length in proportion to movement, in the middle rows of circles drawn for different elevations, and are flanked by circles depicting air movement in HIGHS at the same elevations. No vector was drawn unless three or more observations were included.

In the clear, warm sector (sector 1) southwest winds, veering gradually to west at 4 km. show little variation in direction with the seasons. Here occurs the strongest wind movement below the 2-km. level, velocities being highest in winter and lowest in summer. Taking sectors 2 and 3 into consideration, one would expect a paucity of observations there. Although the majority of the selections made are naturally limited to a low elevation, a surprisingly large number was obtained. The rain area (sector 2) often extends through sector 3 and sometimes into the adjacent HIGH on the northeast, especially in winter. Belief in the probability of the superposed southerly winds overrunning surface easterly winds in these sectors is supported materially by results obtained in a tabulation of cloud direction given in Table 4. With generally light movement throughout, easterly winds at the surface, rapidly turning to south and southwest, are significant. Excepting to some degree in sector 5, in no other region of the Low does there occur the rapid change in wind direction in the lower layers. Sector 4 is marked by a steady northwest wind in all layers, with the highest velocities above the 2-km. level. Little seasonal change in direction occurs. Remarkably high movement appears here in autumn at 3 km. exceeding movement in any part of either wind system. The narrow rain band or squall sector (sector 5) reveals a backing of north and northwest winds at the surface to southwesterly at 2 to 3 km., where they merge with the southwesterly winds of sector 1. Observations by pilot balloons in sector 5 are necessarily few, but the presence of discontinuities is apparent from the frequency with which surface winds shift suddenly from southwesterly to northwest as the Low moves east of the station.

A simultaneous tabulation of free-air winds in HIGHS was obtained, totaling 559 observations. These were taken in all HIGHS showing a well-developed wind circulation. The division into quadrants used by Samuels (2) was employed, excepting that the center was omitted, observations appearing in that region and difficult to assign to any quadrant, being discarded. Figure 2a reveals the shallowness of the effect of disturbing influences in HIGHS, the winds obtaining a nearly common mean direction between 2 and 3 kms. appearing at a much higher elevation in summer than in winter. The greatest change in wind direction aloft in HIGHS occurs in the rear half, quadrant 3 presenting the greatest variability. Winds in that quadrant back from ESE. at the surface through NE. to NW. in spring. In autumn and winter they veer from ESE. through SW. to NW., while in summer an unusually rapid shifting

from SE. to NW. results between 2 and 3 kms. The spring condition may possibly be due to the presence of large bodies of cold water to the east at that season. Change of direction aloft in quadrants 1 and 4 are very slight.

The resultant air movement is greatest in quadrants 1 and 4. The velocities in all quadrants increase rapidly, especially in winter, from the surface to about 750 meters. Above that the increase is very gradual in quadrants 1 and 4. Referring to quadrant 3, the negligible movement appearing at 2 kms. is due to slight excess of opposing winds and does not mean little wind. The results of wind direction in HIGHS as presented here substantially agree with those given by Blair (3) except in the rear half above 3 kms. where a northwest instead of southwest movement is obtained, the differences being probably due to dissimilarity of methods of observation. Graphs of the data in Table 6, and not reproduced here, are in good agreement, and somewhat smoother, with those of Samuels (2).

In connection with this study of winds aloft, a tabulation of cloud distribution and movement was made. Tables 2 and 3 contain data on the frequency percentage of clouds and the percentage of cloudiness in LOWS and HIGHS. Table 4 is a summary of mean cloud directions. The same division of LOWS as used for the study of free-air winds is retained here. Cloudless sky occurs most frequently in the first quadrant of HIGHS and is especially marked in winter. In LOWS cloudless sky is rare, occurring occasionally in sectors 1 and 4. The percentage of cloudiness is highest in the third quadrant of HIGHS and in sectors 2, 3, and 5 of LOWS. The percentages in these sectors are actually much higher than given, as invariably overcast skies prevail in cases where observations are not taken, the data for these tables being abstracted entirely from pilot-balloon observations. Cloudiness is least in the first quadrant of HIGHS with an average of 2.3, and in LOWS in sectors 1 and 4, with the least in sector 1 in summer and sector 4 in winter. The most frequent clouds are Ci., St. Cu., and Cu. Ci. is rarely observed within the areas of sliding surfaces in LOWS, occurring usually in sector 1 of LOWS and generally throughout HIGHS, with a maximum frequency in the rear half of the latter. Their direction of movement (see Table 4) is west in LOWS with a veering to WNW. in HIGHS. Distribution of Ci. St. is very much like that of Ci. A. St. from the expected southwesterly direction occurs throughout LOWS except in sector 4. A. Cu. is fairly evenly distributed, although rarely seen in quadrant 1 of HIGHS and in sectors 2B and 4 of LOWS. They are most frequent in summer. St. Cu. is not seen often in sector 1 of LOWS, but the frequency is quite uniform elsewhere in LOWS. They are of the fair-weather type in sector 4, while elsewhere their range is probably between uniform stratus and distinct Cu. Little differences with season appear in direct contrast to Cu. which has the greatest seasonal variation. Cu. is seldom seen in winter highs and probably never in winter LOWS except infrequently in sector 4. They are conspicuous by their presence in summer, however, occurring as frequently as 83 per cent of the time in the first quadrant of highs and 64 per cent in sector 4 of LOWS. St. is fairly limited to sectors 2 and 3 of LOWS, indicating the character of its formation by forced convection. No tabulation of Nb. is made, observations during their presence being seldom made.

Admitting the limitations placed by the method of using data from a single station, it is believed, however, that the results herein obtained can be accepted quantita-

tively in strengthening the belief in the presence of the primary sliding surfaces in a large number of cyclones passing this region. Southerly air transport over shallow easterly currents in front of the cyclone center disclosed by the illustrations is supported by cloud movement in the intermediate levels. This sliding surface apparently often extends to the limits of the centripetal currents of the cyclone on the northeast and frequently into the adjacent HIGH, where precipitation often results under favorable conditions. Failure to secure many observations in the narrow rain band in the cold season is indicative of occluded fronts, when storms often develop "washbasin low" characteristics. Advance southward of the polar fronts in the cold months naturally results in the development of occluded fronts. Difficulties appear in defining the fronts in the warm summer months when they have retreated farther north and the typical summer flatness appears.

LITERATURE CITED

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Application of the polar-front theory to a series of American weather maps. *Monthly Weather Review*, 54: 485.
- (2) SEMUELS, L. T.
A summary of aerological observations made in well-pronounced HIGHS and LOWS. *Monthly Weather Review*, 54: 195.
- (3) BLAIR, W. R.
1912. Summary of the free-air data obtained at Mount Weather, Va., for the five years, July 1, 1907, to June 30, 1912. *Bulletin of Mount Weather Observatory*, vol. 6, pp. 111-194.

TABLE 1.—Number of observations in "lows" and "highs"

	Winter	Spring	Summer	Autumn	Year
Sector of LOW:					
1.....	23	31	26	34	114
2A.....	6	13	6	12	37
2B.....	17	23	12	21	73
3A.....	1	9	4	5	19
3B.....	17	18	3	6	44
4.....	35	33	33	33	134
5.....	2	2	5	5	14
Quadrant of HIGH:					
1.....	37	28	6	28	99
2.....	25	25	33	56	139
3.....	30	51	60	31	172
4.....	50	39	35	25	149

TABLE 2.—Frequency percentage of clouds, and percentage of cloudiness in lows

Sector	No. cloud	Ci	Ci St	Ci Cu	A St	A Cu	St Cu	Cu	St	Per cent of cloudiness
Winter										
1.....	4	35	26	4	9	17	26	0	4	5.0
2A.....	0	0	17	0	17	0	0	0	50	9.8
2B.....	0	0	0	0	6	0	18	0	71	10.0
3A.....	0	0	12	6	35	23	18	0	28	9.2
3B.....	0	0	9	9	9	11	34	6	9	3.9
4.....	0	20	9	0	0	0	50	0	50	10.0
5.....	0	0	0	0	0	0	0	0	0	0.0
Spring										
1.....	6	26	39	23	6	19	10	19	0	5.3
2A.....	0	8	15	0	15	15	38	8	23	9.4
2B.....	0	0	0	0	35	0	43	0	30	9.8
3A.....	0	44	22	11	22	56	11	44	11	8.0
3B.....	0	17	17	0	39	6	33	17	11	8.9
4.....	0	24	12	6	3	9	24	33	9	5.7
5.....	0	0	0	0	50	0	50	0	0	10.0
Summer										
1.....	15	46	23	8	0	15	8	42	0	4.0
2A.....	0	0	0	0	23	67	67	0	17	9.5
2B.....	0	0	17	8	8	33	50	33	17	8.6
3A.....	0	25	50	50	25	0	0	25	0	8.2
3B.....	0	0	0	0	33	67	33	33	0	8.7
4.....	3	24	6	6	6	0	21	64	0	5.2
5.....	0	20	40	20	40	20	20	40	0	8.2

TABLE 2.—Frequency percentage of clouds, and percentage of cloudiness in lows—Continued

Sector	No. cloud	C	CiSt	CiCu	A St	A Cu	StCu	Cu	St	Per cent of cloudiness
Autumn										
1.....	6	38	21	18	15	21	15	26	3	5.0
2A.....	0	0	0	0	17	8	33	8	50	9.1
2B.....	0	0	0	5	29	10	48	0	33	9.8
3A.....	0	0	20	0	40	20	40	0	40	9.6
3B.....	0	33	17	0	33	17	33	17	17	9.2
4.....	0	15	6	0	12	9	57	12	6	6.8
5.....	0	0	0	0	40	20	60	0	0	9.8
Year										
1.....	8	36	27	14	8	18	14	23	2	4.9
2A.....	0	3	8	0	19	19	35	5	35	9.3
2B.....	0	0	3	3	22	8	40	5	38	9.7
3A.....	0	26	28	16	32	32	16	26	16	8.5
3B.....	0	11	9	2	36	18	27	11	16	9.0
4.....	3	21	8	5	7	5	34	28	6	5.4
5.....	0	7	14	0	36	14	43	14	7	9.3

TABLE 3.—Frequency percentage of clouds and percentage of cloudiness in highs

Quadrant	No. cloud	Ci	CiSt	CiCu	A St	A Cu	StCu	Cu	St	Per cent of cloudiness
Winter										
1.....	38	8	14	5	16	5	11	3	0	1.4
2.....	12	40	12	20	12	16	12	0	4	4.6
3.....	7	33	20	3	13	27	17	7	13	6.2
4.....	12	18	20	12	22	18	20	10	4	5.1
Spring										
1.....	32	21	7	7	7	4	7	18	0	1.4
2.....	8	56	24	4	20	24	8	28	0	5.8
3.....	10	39	29	6	14	16	12	20	2	4.9
4.....	13	23	18	0	8	10	21	31	0	4.0
Summer										
1.....	17	0	0	0	0	0	17	83	0	4.8
2.....	12	36	18	3	12	24	3	39	0	4.5
3.....	5	57	13	10	18	20	15	35	0	4.8
4.....	6	29	11	3	0	17	17	64	6	4.5
Autumn										
1.....	25	14	0	4	14	0	25	29	4	4.0
2.....	18	30	29	5	14	21	14	11	2	3.7
3.....	10	32	19	13	6	13	10	26	3	5.1
4.....	4	16	12	0	4	12	32	28	8	5.3
Year										
1.....	37	13	7	5	12	3	14	19	1	2.3
2.....	14	38	22	7	14	22	10	19	1	4.4
3.....	8	43	20	8	14	19	13	24	3	5.1
4.....	9	21	16	5	10	15	21	29	4	4.7

TABLE 4.—Mean direction of clouds in "lows" and "highs"

	Ci	CiSt	CiCu	A St	A Cu	StCu	Cu	St
Sector of low:								
1.....	W.	W.	W.	WSW.	WSW.	WSW.	SW.	SW.
2A.....	W.	W.	W.	SW.	SW.	SSW.	S.	SSE.
2B.....	W.	W.	WSW.	WSW.	W.	SE.	SW.	ESE.
3A.....	WSW.	WSW.	SW.	WSW.	SW.	SSE.	SSE.	SSW.
3B.....	W.	WSW.	W.	SW.	SW.	ESE.	N.	E.
4.....	W.	W.	WNW.	WNW.	WNW.	NW.	NW.	NNW.
5.....	W.	WNW.	NW.	WSW.	W.	SW.	W.	WNW.
Quadrant of high:								
1.....	WNW.	WNW.	WNW.	NW.	WNW.	NW.	NW.	W.
2.....	WNW.	W.	W.	W.	W.	SW.	SSW.	SW.
3.....	WNW.	W.	W.	W.	WNW.	SSE.	ENE.	S.
4.....	WNW.	W.	WNW.	NW.	NW.	NNW.	NNW.	NNE.

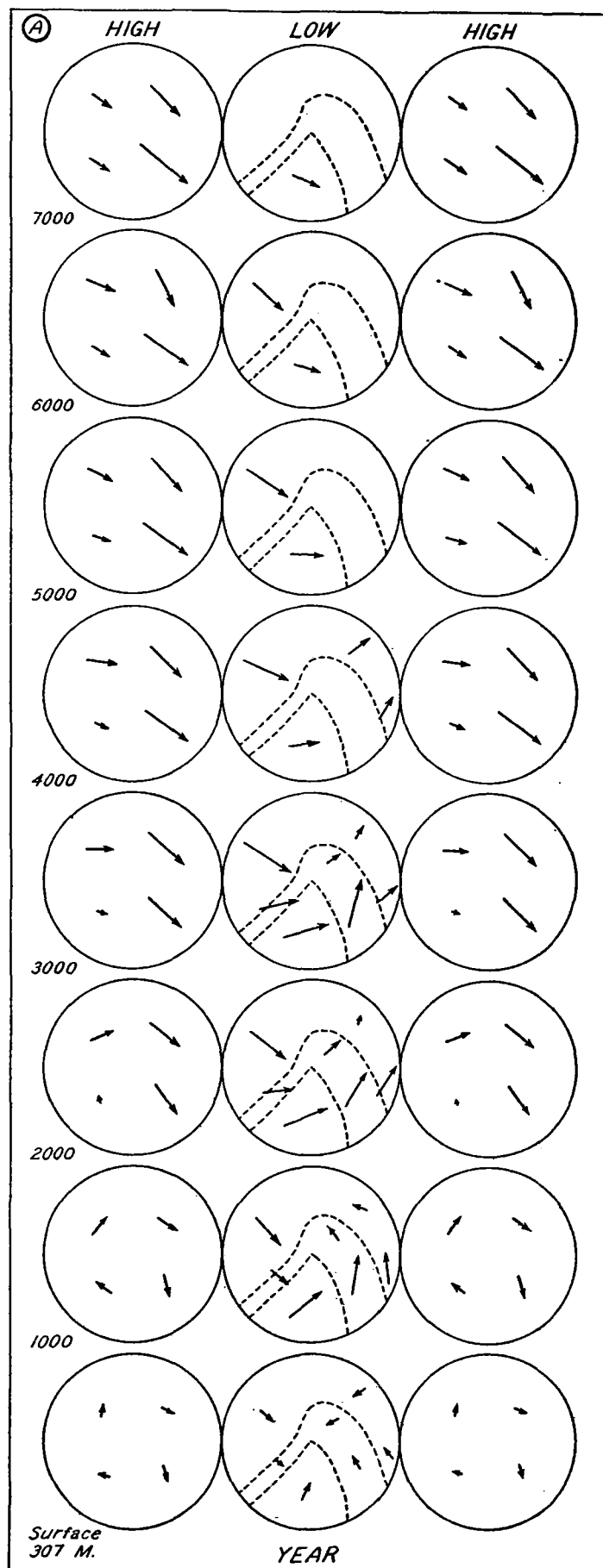


FIG. 2.—Free-air resultant winds in Lows and Highs

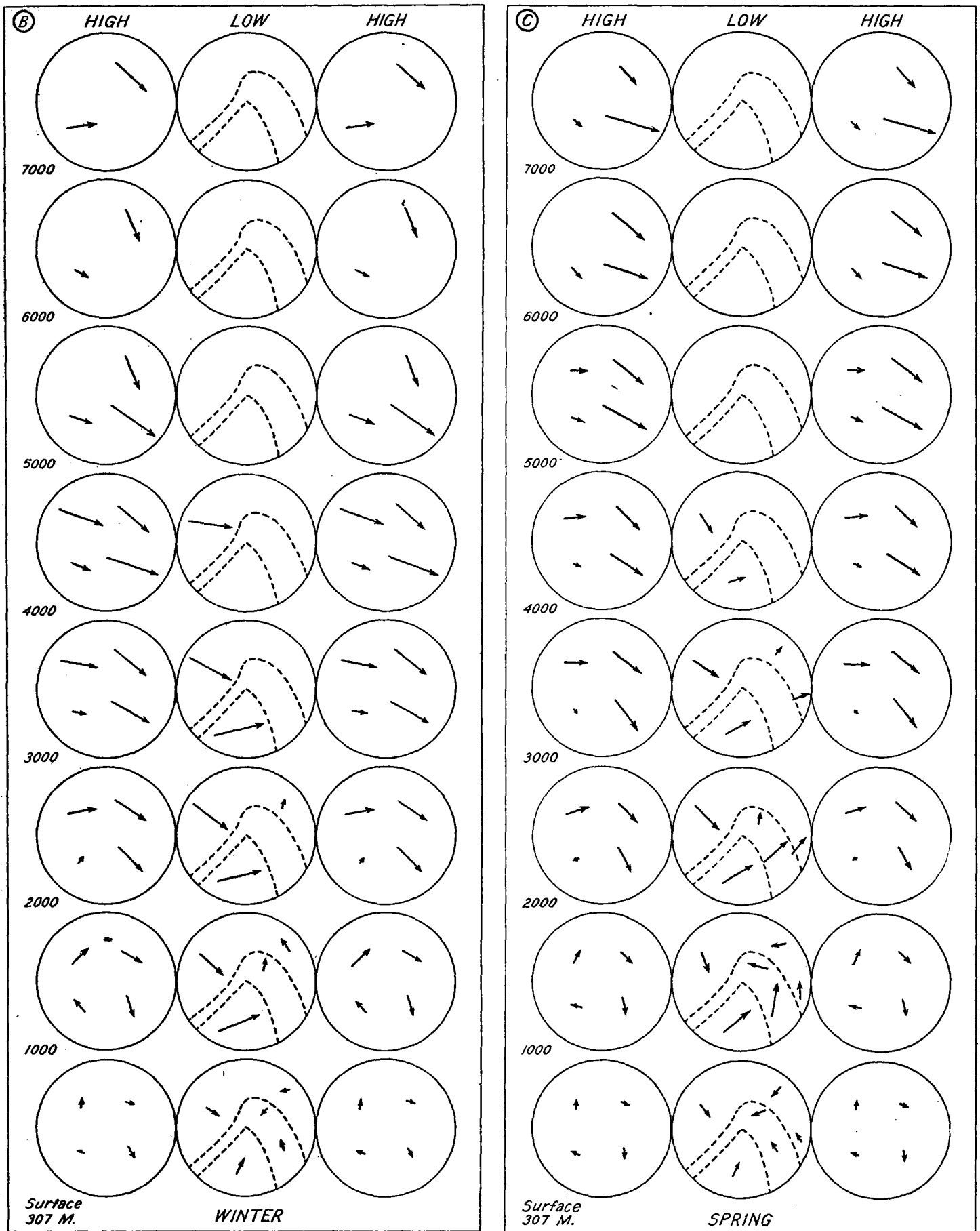


FIG. 2.—Free-air resultant winds in lows and highs

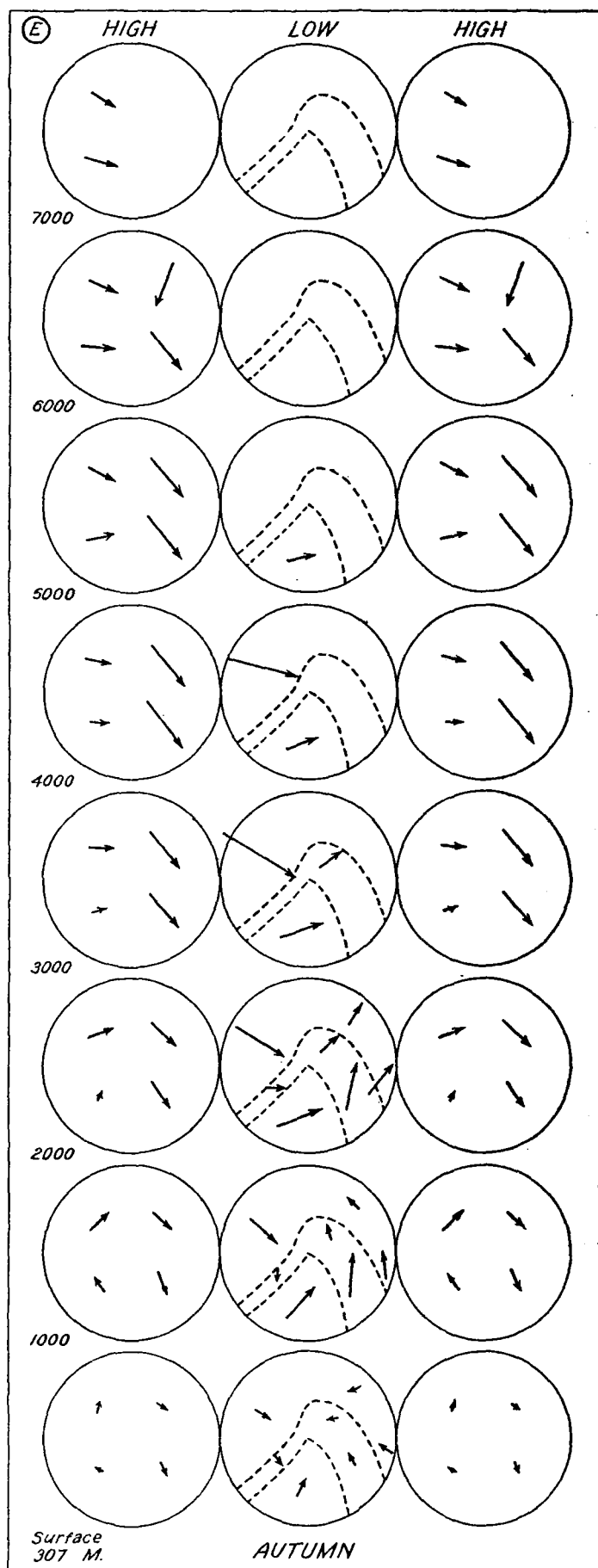
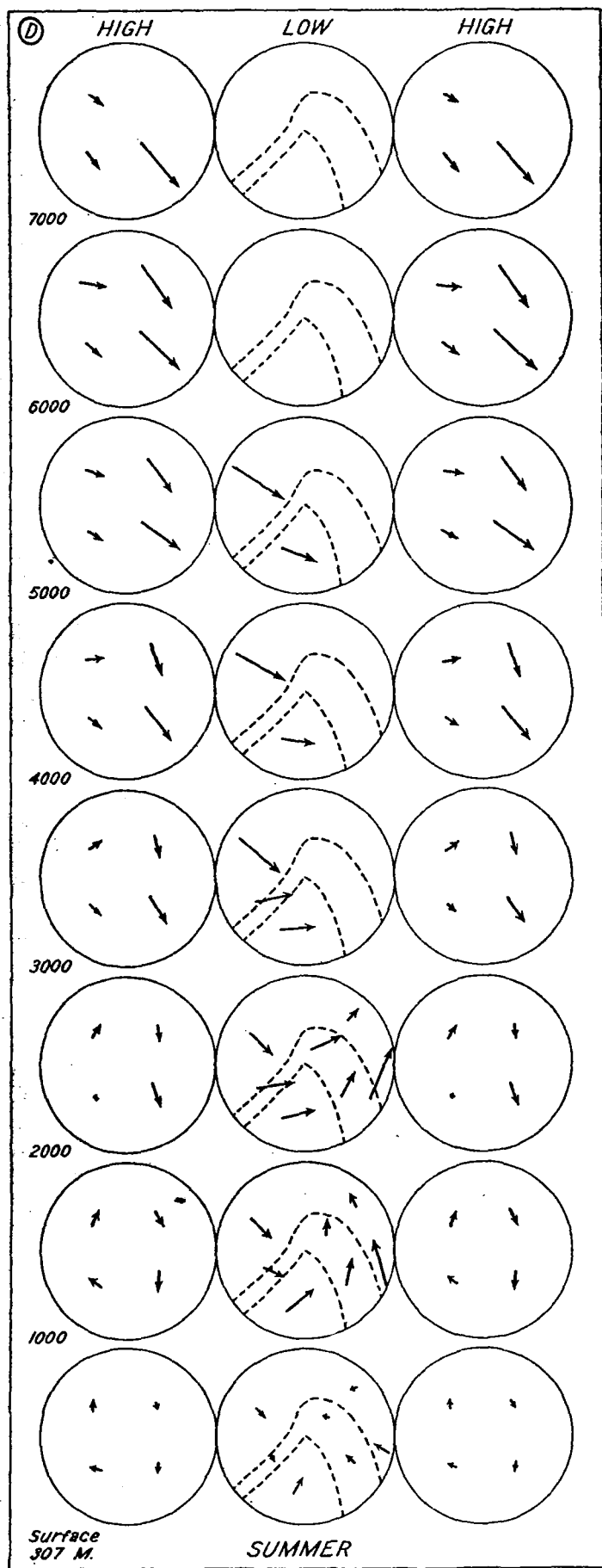


FIG. 2.—Free-air resultant winds in LOWS and HIGHS

TABLE 5.—Free-air resultant winds in "lows"
WINTER

Altitude m. s. l.	Sector 1	Sector 2A	Sector 2B	Sector 3A	Sector 3B	Sector 4	Sector 5
Surface	S. 26° W. 6.0	S. 19° E. 4.4	N. 44° E. 3.7	-----	N. 76° E. 3.5	N. 56° W. 5.9	-----
500	S. 34° W. 11.1	S. 22° E. 10.2	N. 63° E. 4.5	-----	N. 87° E. 5.1	N. 55° W. 8.6	-----
750	S. 55° W. 15.7	S. 14° E. 8.1	S. 62° E. 3.9	-----	S. 66° E. 6.4	N. 53° W. 1.2	-----
1,000	S. 68° W. 17.0	-----	S. 10° W. 5.0	-----	S. 34° E. 6.5	N. 47° W. 13.0	-----
1,500	S. 74° W. 16.2	-----	S. 48° W. 6.6	-----	S. 7° W. 7.5	N. 47° W. 15.6	-----
2,000	S. 77° W. 17.5	-----	-----	-----	S. 16° W. 7.6	N. 54° W. 16.6	-----
2,500	S. 80° W. 18.4	-----	-----	-----	S. 5.2	N. 58° W. 19.0	-----
3,000	S. 76° W. 19.5	-----	-----	-----	-----	N. 62° W. 17.3	-----
3,500	-----	-----	-----	-----	-----	N. 71° W. 14.3	-----
4,000	-----	-----	-----	-----	-----	N. 81° W. 17.4	-----

SPRING

Surface	S. 25° W. 6.7	S. 32° E. 4.6	N. 64° E. 5.5	S. 36° E. 4.3	N. 42° E. 5.5	N. 36° W. 5.1	-----
500	S. 23° W. 10.6	S. 19° E. 8.5	N. 77° E. 7.5	S. 32° E. 6.4	N. 53° E. 6.0	N. 39° W. 8.2	-----
750	S. 40° W. 13.5	S. 2° E. 11.7	S. 79° E. 8.8	S. 29° E. 6.8	N. 73° E. 6.3	N. 36° W. 9.7	-----
1,000	S. 49° W. 13.8	S. 9° W. 13.4	S. 75° E. 7.9	S. 4° E. 7.2	N. 76° E. 5.8	N. 18° W. 7.8	-----
1,500	S. 60° W. 12.7	S. 21° W. 13.7	S. 13° E. 7.3	S. 30° W. 9.6	N. 87° E. 4.2	N. 40° W. 9.8	-----
2,000	S. 58° W. 13.2	S. 47° W. 13.6	S. 10° W. 4.2	S. 39° W. 9.7	S. 30° E. 1.6	N. 45° W. 12.0	-----
2,500	S. 60° W. 12.5	-----	-----	S. 38° W. 9.2	S. 70° W. 3.2	N. 56° W. 12.2	-----
3,000	S. 58° W. 10.3	-----	-----	S. 71° W. 7.6	S. 33° W. 3.1	N. 57° W. 11.2	-----
3,500	S. 56° W. 9.1	-----	-----	S. 69° W. 6.4	N. 44° W. 8.6	N. 38° W. 11.6	-----
4,000	S. 70° W. 6.4	-----	-----	-----	-----	N. 33° W. 8.9	-----
4,500	S. 67° W. 5.8	-----	-----	-----	-----	-----	-----

SUMMER

Surface	S. 32° W. 5.3	S. 45° E. 2.5	S. 78° E. 2.0	S. 32° E. 5.4	N. 64° E. 2.4	N. 40° W. 4.6	N. 31° W. 2.5
500	S. 38° W. 8.8	S. 6° E. 5.1	S. 68° E. 3.0	S. 22° E. 9.3	S. 86° E. 5.1	N. 45° W. 6.7	N. 47° W. 4.8
750	S. 43° W. 10.5	S. 7° W. 7.0	S. 32° E. 3.2	S. 16° E. 12.3	S. 67° E. 4.4	N. 45° W. 8.8	N. 51° W. 7.1
1,000	S. 50° W. 10.5	S. 11° W. 8.7	S. 3° W. 4.5	S. 15° E. 14.3	S. 64° E. 4.1	N. 47° W. 9.1	N. 64° W. 7.2
1,500	S. 57° W. 10.6	S. 17° W. 10.1	S. 56° W. 5.8	S. 16° W. 16.0	S. 6° E. 4.2	N. 47° W. 9.3	N. 87° W. 11.0
2,000	S. 74° W. 10.8	S. 29° W. 8.2	S. 63° W. 9.9	S. 22° W. 16.7	S. 40° W. 4.3	N. 46° W. 9.4	S. 76° W. 11.1
2,500	S. 81° W. 10.5	-----	-----	-----	S. 74° W. 6.9	N. 51° W. 12.3	S. 64° W. 9.6
3,000	S. 84° W. 10.7	-----	-----	-----	-----	N. 49° W. 14.6	S. 73° W. 10.6
3,500	N. 86° W. 9.1	-----	-----	-----	-----	N. 57° W. 15.4	-----
4,000	N. 82° W. 8.2	-----	-----	-----	-----	N. 60° W. 16.1	-----
4,500	N. 81° W. 10.9	-----	-----	-----	-----	N. 63° W. 15.1	-----
5,000	N. 69° W. 11.2	-----	-----	-----	-----	N. 57° W. 17.4	-----

AUTUMN

Surface	S. 24° W. 6.0	S. 31° E. 4.3	N. 81° E. 2.7	S. 55° E. 4.8	N. 65° E. 3.4	N. 52° W. 5.6	N. 35° W. 3.3
500	S. 30° W. 10.0	S. 18° E. 9.2	S. 65° E. 4.2	S. 52° E. 6.6	S. 7° E. 4.7	N. 47° W. 8.8	N. 37° W. 6.1
750	S. 32° W. 11.8	S. 15° E. 12.0	S. 35° E. 4.5	S. 22° E. 7.5	S. 65° E. 5.2	N. 46° W. 10.4	N. 22° W. 5.8
1,000	S. 41° W. 12.5	S. 5° W. 13.6	S. 19° E. 4.9	S. 7° E. 9.5	S. 42° E. 5.3	N. 48° W. 11.0	N. 1° E. 4.6
1,500	S. 56° W. 14.3	S. 20° W. 14.9	S. 8° W. 4.7	S. 27° W. 12.9	S. 8° E. 4.5	N. 57° W. 11.3	N. 35° W. 2.9
2,000	S. 66° W. 14.2	S. 12° W. 15.2	S. 47° W. 7.0	S. 37° W. 12.2	S. 35° W. 7.2	N. 59° W. 17.2	N. 89° W. 5.1
2,500	S. 71° W. 14.4	-----	S. 54° W. 9.4	S. 37° W. 13.9	S. 35° W. 11.1	N. 57° W. 19.0	-----
3,000	S. 69° W. 13.3	-----	S. 51° W. 9.4	-----	-----	N. 59° W. 23.7	-----
3,500	S. 70° W. 11.9	-----	-----	-----	-----	N. 65° W. 21.7	-----
4,000	S. 67° W. 10.5	-----	-----	-----	-----	N. 76° W. 20.6	-----
4,500	S. 65° W. 11.0	-----	-----	-----	-----	-----	-----
5,000	S. 75° W. 9.7	-----	-----	-----	-----	-----	-----

YEAR

Surface	S. 26° W. 6.0	S. 30° E. 4.1	N. 65° E. 3.5	S. 38° E. 4.8	N. 56° E. 4.1	N. 47° W. 5.2	N. 52° W. 2.9
500	S. 34° W. 10.1	S. 23° E. 6.7	S. 86° E. 4.8	S. 31° E. 7.3	N. 72° E. 5.2	N. 47° W. 8.1	N. 58° W. 5.9
750	S. 42° W. 12.6	S. 5° E. 10.2	S. 61° E. 5.2	S. 18° E. 8.4	S. 84° E. 5.7	N. 45° W. 10.0	N. 53° W. 7.6
1,000	S. 51° W. 12.9	S. 8° W. 11.9	S. 38° E. 4.8	S. 6° E. 9.8	S. 67° E. 4.9	N. 41° W. 10.0	N. 48° W. 6.5
1,500	S. 61° W. 13.2	S. 20° W. 12.6	S. 15° W. 5.2	S. 25° W. 11.6	S. 36° E. 3.9	N. 48° W. 11.3	N. 84° W. 7.5
2,000	S. 68° W. 13.4	S. 32° W. 12.2	S. 44° W. 6.3	S. 33° W. 11.8	S. 15° W. 3.8	N. 51° W. 13.3	S. 81° W. 8.3
2,500	S. 72° W. 13.0	S. 18° W. 11.7	S. 49° W. 7.9	S. 40° W. 12.1	S. 49° W. 4.8	N. 56° W. 15.3	S. 75° W. 10.0
3,000	S. 73° W. 13.0	S. 14° W. 15.4	S. 55° W. 5.7	S. 48° W. 7.8	S. 30° W. 5.0	N. 57° W. 16.1	S. 76° W. 12.2
3,500	S. 75° W. 10.6	-----	-----	S. 57° W. 7.3	N. 86° W. 7.0	N. 58° W. 14.7	S. 68° W. 11.7
4,000	S. 81° W. 8.8	-----	-----	S. 30° W. 7.6	S. 51° W. 8.4	N. 66° W. 15.0	-----
4,500	S. 79° W. 9.2	-----	-----	-----	-----	N. 59° W. 13.5	-----
5,000	N. 86° W. 9.7	-----	-----	-----	-----	N. 57° W. 15.4	-----
6,000	N. 72° W. 8.6	-----	-----	-----	-----	N. 47° W. 12.9	-----
7,000	N. 65° W. 9.6	-----	-----	-----	-----	-----	-----

TABLE 6.—Free-air resultant winds in "highs"

WINTER				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Surface.....	N. 79° W. 3.8	S. 10° W. 3.9	S. 72° E. 2.5	N. 29° W. 4.7
500.....	N. 72° W. 5.7	S. 21° W. 6.3	S. 68° E. 3.8	N. 26° W. 6.6
750.....	N. 66° W. 7.4	S. 34° W. 8.3	S. 56° E. 5.3	N. 14° W. 6.6
1,000.....	N. 60° W. 8.8	S. 46° W. 9.6	S. 42° E. 6.2	N. 19° W. 8.7
1,500.....	N. 55° W. 11.7	S. 52° W. 11.0	S. 36° E. 3.5	N. 38° W. 10.6
2,000.....	N. 55° W. 14.0	S. 78° W. 11.0	S. 35° W. 3.0	N. 44° W. 13.7
2,500.....	N. 55° W. 16.7	S. 85° W. 12.2	W. 4.1	N. 58° W. 16.4
3,000.....	N. 51° W. 18.6	N. 79° W. 14.6	N. 79° W. 6.1	N. 60° W. 16.6
3,500.....	N. 49° W. 15.1	N. 72° W. 10.0	N. 78° W. 6.7	N. 59° W. 18.6
4,000.....	N. 49° W. 15.2	N. 71° W. 17.3	N. 68° W. 7.5	N. 70° W. 20.6
4,500.....	N. 44° W. 13.5	N. 68° W. 19.2	N. 77° W. 8.9	N. 59° W. 21.4
5,000.....	N. 23° W. 12.7	-----	N. 61° W. 9.6	N. 64° W. 20.4
6,000.....	N. 23° W. 12.5	-----	N. 61° W. 6.0	-----
7,000.....	N. 47° W. 15.9	-----	S. 80° W. 11.2	-----
8,000.....	-----	-----	S. 89° W. 8.9	-----
9,000.....	-----	-----	-----	-----

SPRING				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Surface.....	N. 65° W. 3.2	S. 6° W. 3.8	S. 69° E. 3.2	N. 8° W. 4.3
500.....	N. 61° W. 4.6	S. 14° W. 6.1	S. 71° E. 4.5	N. 9° W. 5.6
750.....	N. 50° W. 5.3	S. 16° W. 7.0	S. 78° E. 4.7	N. 11° W. 6.2
1,000.....	N. 49° W. 6.2	S. 26° W. 6.7	S. 73° E. 4.5	N. 13° W. 6.7
1,500.....	N. 46° W. 8.4	S. 52° W. 7.6	S. 71° E. 3.3	N. 18° W. 8.6
2,000.....	N. 46° W. 10.2	S. 71° W. 8.4	N. 66° E. 1.5	N. 28° W. 10.6
2,500.....	N. 47° W. 11.6	S. 81° W. 8.3	N. 2° E. 1.1	N. 33° W. 12.0
3,000.....	N. 50° W. 13.2	W. 9.4	N. 47° W. 1.8	N. 37° W. 14.4
3,500.....	N. 49° W. 13.5	S. 86° W. 9.5	N. 30° W. 1.8	N. 56° W. 16.0
4,000.....	N. 46° W. 12.3	S. 83° W. 9.0	N. 68° W. 3.7	N. 56° W. 14.8
4,500.....	N. 49° W. 12.8	S. 73° W. 5.8	N. 67° W. 6.2	N. 53° W. 15.6
5,000.....	N. 52° W. 15.0	W. 7.1	N. 66° W. 5.3	N. 61° W. 13.1
6,000.....	N. 51° W. 14.8	-----	N. 43° W. 5.8	N. 71° W. 18.0
7,000.....	N. 43° W. 10.0	-----	N. 50° W. 4.5	N. 72° W. 21.9
8,000.....	N. 68° W. 12.3	-----	N. 39° W. 11.2	-----
9,000.....	-----	-----	N. 52° W. 16.9	-----

SUMMER				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Surface.....	N. 25° W. 2.6	S. 2° E. 3.0	S. 77° E. 2.4	N. 7° E. 3.6
500.....	N. 33° W. 4.7	S. 12° W. 4.9	S. 68° E. 3.8	N. 9° E. 5.1
750.....	N. 27° W. 5.4	S. 20° W. 5.0	S. 61° E. 4.5	N. 8° E. 5.1
1,000.....	N. 25° W. 5.3	S. 21° W. 4.9	S. 56° E. 4.0	N. 8° E. 5.0
1,500.....	N. 7° W. 4.4	S. 28° W. 5.2	S. 51° E. 2.8	N. 8° W. 6.4
2,000.....	N. 3° W. 4.6	S. 34° W. 4.5	S. 64° E. 0.4	N. 19° W. 7.7
2,500.....	N. 13° W. 5.8	S. 47° W. 4.7	N. 60° W. 1.4	N. 28° W. 8.1
3,000.....	N. 12° W. 6.8	S. 56° W. 4.7	N. 46° W. 3.2	N. 32° W. 9.7
3,500.....	N. 13° W. 7.9	S. 72° W. 5.5	N. 53° W. 3.9	N. 38° W. 11.8
4,000.....	N. 19° W. 10.4	N. 89° W. 5.3	N. 55° W. 4.3	N. 39° W. 12.9
4,500.....	N. 23° W. 11.8	N. 81° W. 5.3	N. 57° W. 5.0	N. 50° W. 14.8
5,000.....	N. 35° W. 12.7	N. 76° W. 5.6	N. 62° W. 5.7	N. 63° W. 14.2
6,000.....	N. 33° W. 14.2	N. 82° W. 7.3	N. 52° W. 6.7	N. 45° W. 16.6

TABLE 6.—Free-air resultant winds in "highs"—Continued

SUMMER—Continued				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
7,000.....	-----	N. 55° W. 5.0	N. 38° W. 7.3	N. 41° W. 16.6
8,000.....	-----	-----	N. 44° W. 7.9	-----
9,000.....	-----	-----	N. 58° W. 6.8	-----
10,000.....	-----	-----	N. 47° W. 6.0	-----
11,000.....	-----	-----	N. 33° E. 5.0	-----
12,000.....	-----	-----	N. 8.7	-----

AUTUMN				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Surface.....	N. 51° W. 3.6	S. 19° W. 3.5	S. 55° E. 2.4	N. 23° W. 4.2
500.....	N. 50° W. 5.6	S. 30° W. 6.1	S. 51° E. 4.5	N. 20° W. 5.1
750.....	N. 47° W. 6.4	S. 39° W. 7.0	S. 40° E. 5.4	N. 20° W. 5.2
1,000.....	N. 47° W. 7.1	S. 46° W. 7.5	S. 34° E. 5.4	N. 22° W. 7.8
1,500.....	N. 42° W. 8.2	S. 56° W. 8.3	S. 13° E. 4.7	N. 25° W. 8.1
2,000.....	N. 46° W. 10.5	S. 69° W. 8.2	S. 21° W. 2.7	N. 32° W. 9.2
2,500.....	N. 44° W. 12.6	S. 83° W. 7.5	S. 64° W. 3.6	N. 36° W. 11.2
3,000.....	N. 38° W. 13.8	N. 86° W. 7.2	S. 74° W. 4.7	N. 41° W. 13.4
3,500.....	N. 39° W. 15.8	N. 83° W. 8.0	S. 79° W. 5.4	N. 43° W. 14.5
4,000.....	N. 39° W. 15.4	N. 78° W. 7.7	N. 85° W. 5.6	N. 37° W. 17.6
4,500.....	N. 36° W. 17.4	N. 73° W. 7.5	W. 7.1	N. 38° W. 17.3
5,000.....	N. 40° W. 15.8	N. 62° W. 8.6	S. 77° W. 8.7	N. 37° W. 16.7
6,000.....	N. 21° E. 14.3	N. 65° W. 9.5	N. 85° W. 9.7	N. 38° W. 14.0
7,000.....	-----	N. 58° W. 7.9	N. 72° W. 10.9	-----
8,000.....	-----	N. 48° W. 7.6	-----	-----
9,000.....	-----	N. 60° W. 7.1	-----	-----
10,000.....	-----	N. 40° W. 2.9	-----	-----

YEAR				
Altitude m. s. l.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4
Surface.....	N. 65° W. 3.4	S. 10° W. 3.5	S. 76° E. 2.6	N. 15° W. 4.1
500.....	N. 61° W. 5.1	S. 22° W. 5.8	S. 69° E. 4.1	N. 14° W. 5.6
750.....	N. 55° W. 6.2	S. 30° W. 6.7	S. 61° E. 4.7	N. 9° W. 6.1
1,000.....	N. 53° W. 7.3	S. 39° W. 7.0	S. 54° E. 4.6	N. 13° W. 7.1
1,500.....	N. 49° W. 9.3	S. 52° W. 7.7	S. 43° E. 3.0	N. 25° W. 8.5
2,000.....	N. 50° W. 11.3	S. 67° W. 7.6	S. 12° E. 0.6	N. 34° W. 10.6
2,500.....	N. 49° W. 13.3	S. 79° W. 7.4	N. 77° W. 1.6	N. 44° W. 12.2
3,000.....	N. 46° W. 13.6	W. 7.8	N. 68° W. 3.0	N. 46° W. 13.7
3,500.....	N. 45° W. 14.1	W. 8.6	N. 68° W. 3.3	N. 51° W. 15.2
4,000.....	N. 42° W. 13.7	N. 82° W. 8.4	N. 67° W. 4.7	N. 53° W. 15.8
4,500.....	N. 40° W. 14.3	N. 76° W. 77.8	N. 71° W. 6.1	N. 51° W. 16.4
5,000.....	N. 41° W. 14.1	N. 66° W. 8.1	N. 74° W. 6.4	N. 53° W. 16.7
6,000.....	N. 26° W. 12.8	N. 68° W. 9.2	N. 60° W. 6.7	N. 53° W. 16.4
7,000.....	N. 42° W. 12.6	N. 57° W. 7.2	N. 58° W. 7.3	N. 51° W. 13.4
8,000.....	N. 40° W. 11.7	N. 55° W. 7.0	N. 53° W. 8.1	-----
9,000.....	N. 6° W. 11.2	N. 60° W. 7.1	N. 59° W. 8.4	-----
10,000.....	-----	N. 40° W. 2.9	N. 72° W. 7.8	-----
11,000.....	-----	-----	N. 36° W. 3.4	-----
12,000.....	-----	-----	N. 43° W. 8.0	-----

STATISTICAL CORRELATIONS OF WEATHER INFLUENCE ON CROP YIELDS

By J. B. KINCER and W. A. MATTICE

(Weather Bureau, Washington, D. C., March 14, 1928)

At the April, 1927, meeting of the American Meteorological Society, in Washington, the senior author outlined a method of multiple correlations of weather data with crop yields, that, so far as known, has not been employed heretofore by investigators in this field. The data used were several phases of weather in North Dakota in relation to the yield of spring wheat in that State, and since that presentation the authors, jointly, have applied the method to other crops in different States, and on weekly, biweekly, and monthly units of time for the weather variants, with very satisfactory results.

Weather, in the aggregate, for a given period of time as affecting plant growth, is a composite of many phases, such as temperature, rainfall, sunshine, wind, relative humidity, etc. There are also subphases, such as the mean temperature, mean of the daily maxima and of the daily minima, mean daily range, etc. Growing crops are influenced more or less by all of these phases which, in combination, make up the weather of the season. It is also well known that there are critical periods of growth, during which certain weather influences are more marked

than during other times. These critical periods, in some crops at least, are of comparatively short duration and, consequently, it is necessary for best results to use weather variants based on similar short intervals of time, that their greater importance may be reflected in the final result. In most weather and crop correlations the month is used as the basic unit of time, principally by reason of the fact that weather data are usually compiled and published in this way. It is preferable, however, that shorter intervals of time be used in most cases.

The limitations of statistical correlations in studying the influence of weather on crops obtain, to a considerable extent, because of the large number of weather phases, all, or most of which, apparently have more or less influence on yield, and also because of the varying importance of different periods of growth, necessitating the use of comparatively short time intervals. These, combined, usually give a much larger number of variants than can be handled conveniently by the usual correlation methods. The system used in this study segregates, or picks out, from a large number of weather variants, those which, in combination with certain others, contribute to the aug-